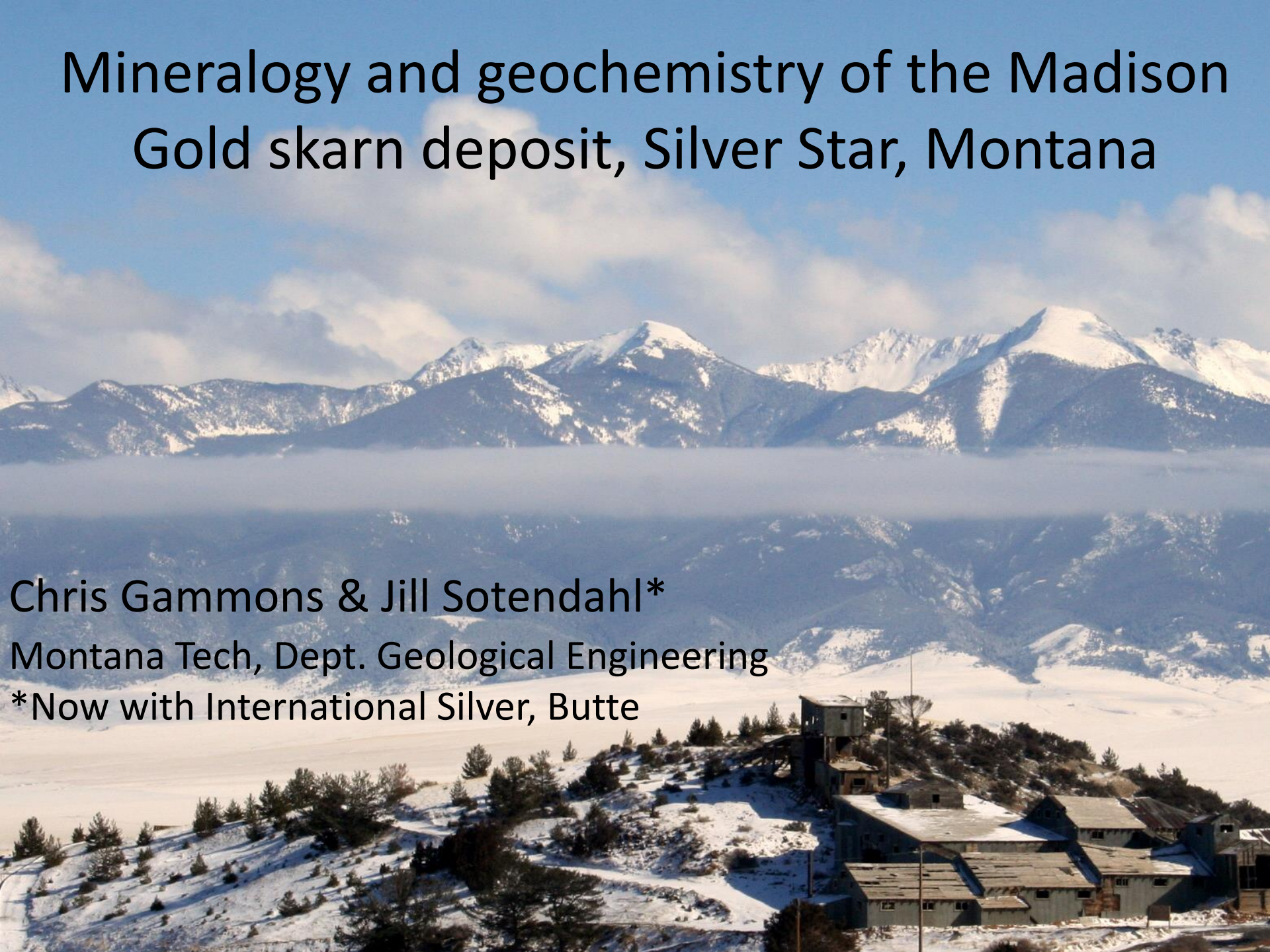
Mineralogy and geochemistry of the Madison Gold skarn deposit, Silver Star, Montana



Chris Gammons & Jill Sotendahl*

Montana Tech, Dept. Geological Engineering

*Now with International Silver, Butte

Madison Gold skarn deposit

Historic Broadway Mine, Silver Star

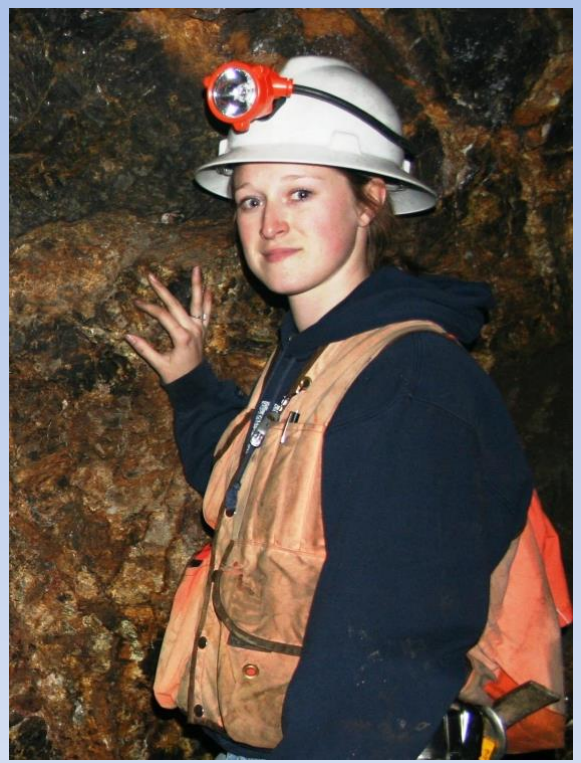
- 1880's to 1950's
- ~ 150K ounces gold @ 0.32 opt

Coronado acquires property

- 2005-2006: Drilling
- 2007: Begin underground development
- 2007-2012 production*:
  - 7570 oz gold
  - 2.68 M lbs copper

Jill Sotendahl (2012) M.S. Thesis

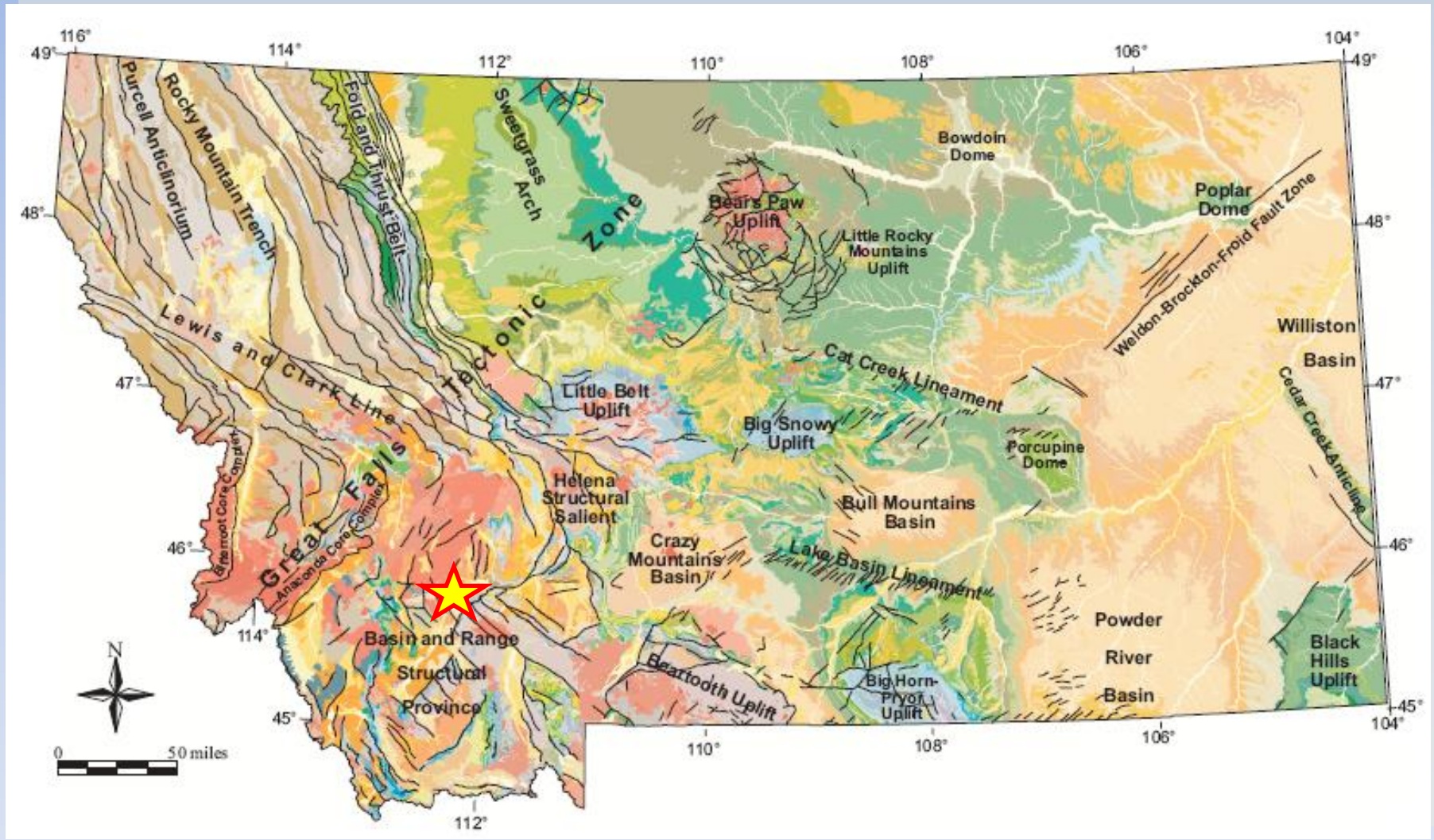
- Mineralogy and geochemistry



Jill: now with International Silver, Butte

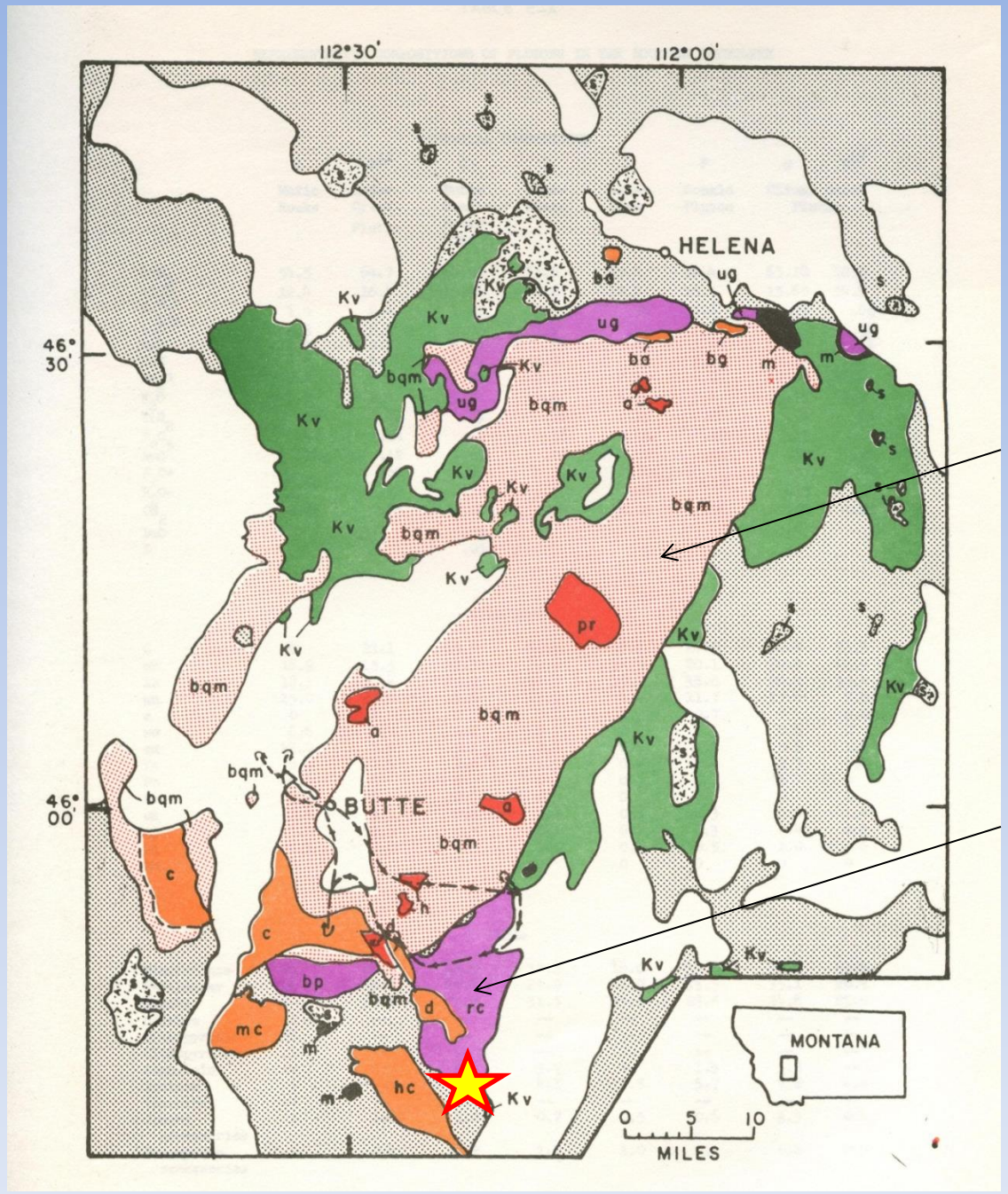
* Dan Everett, pers. comm. May, 2013

Location within Montana



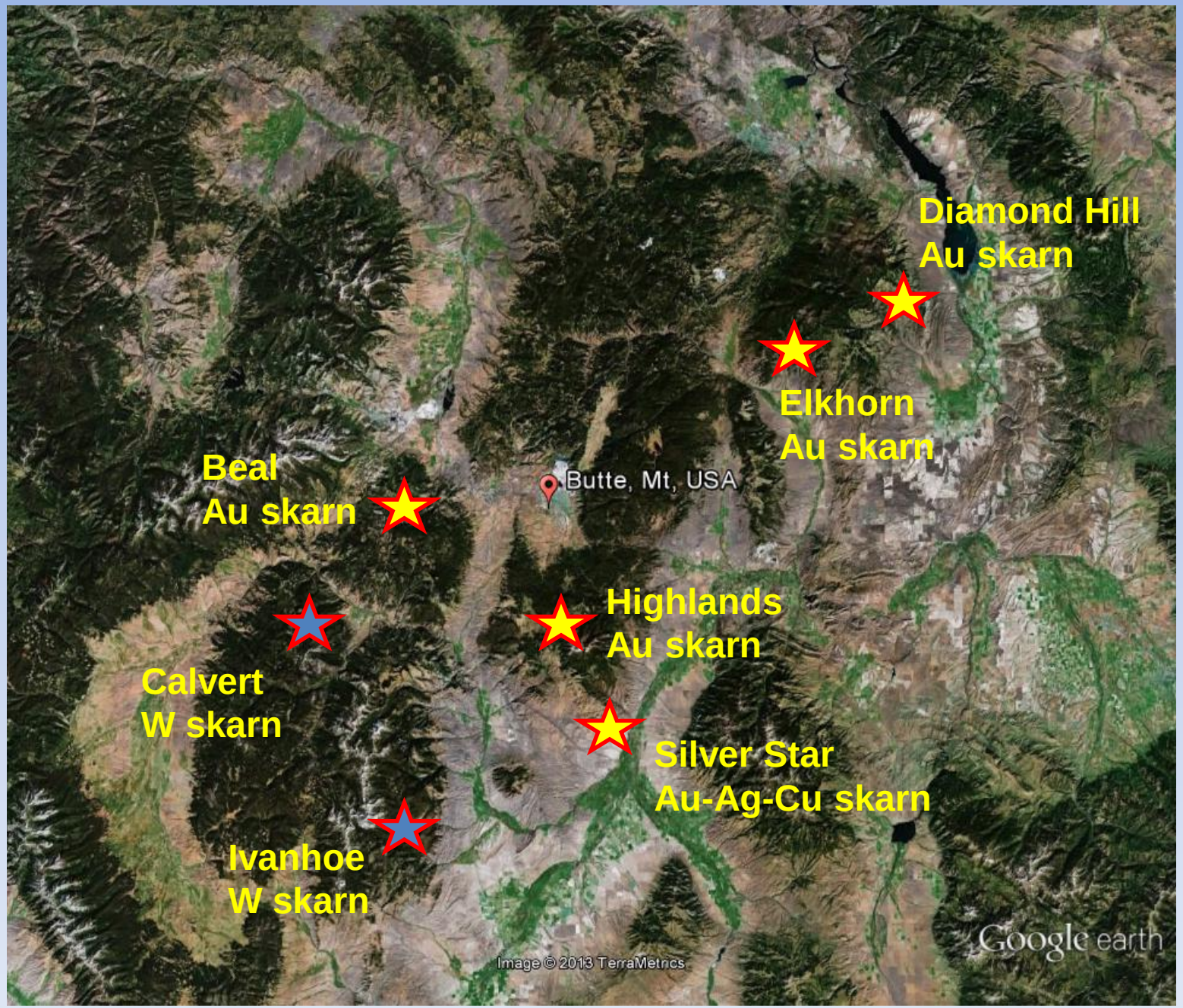
Boulder Batholith

Smedes et al. 1973

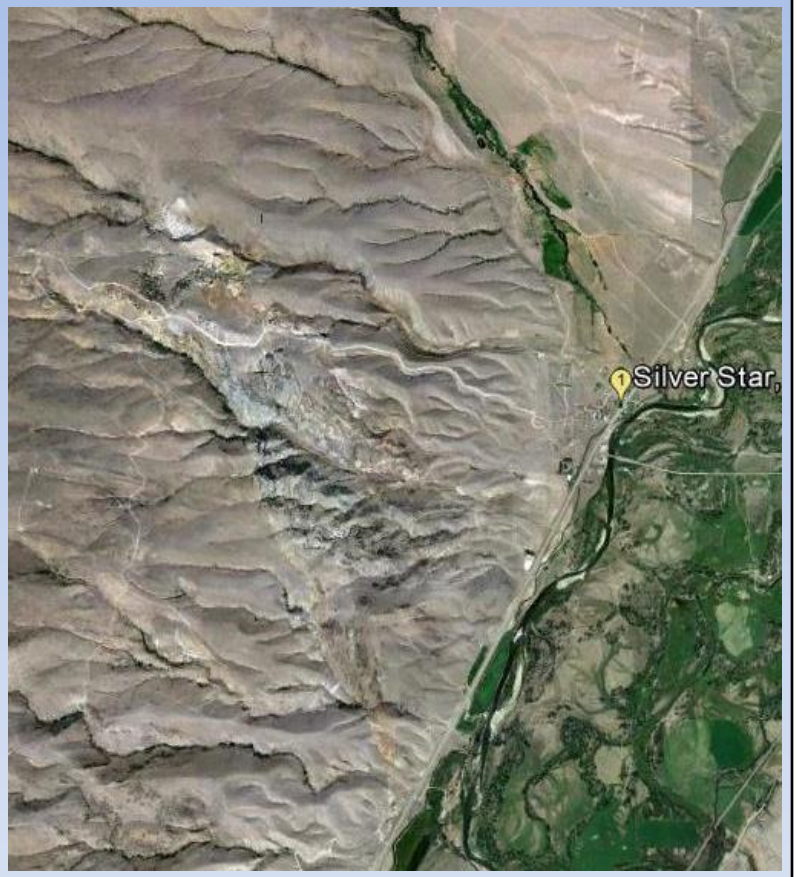


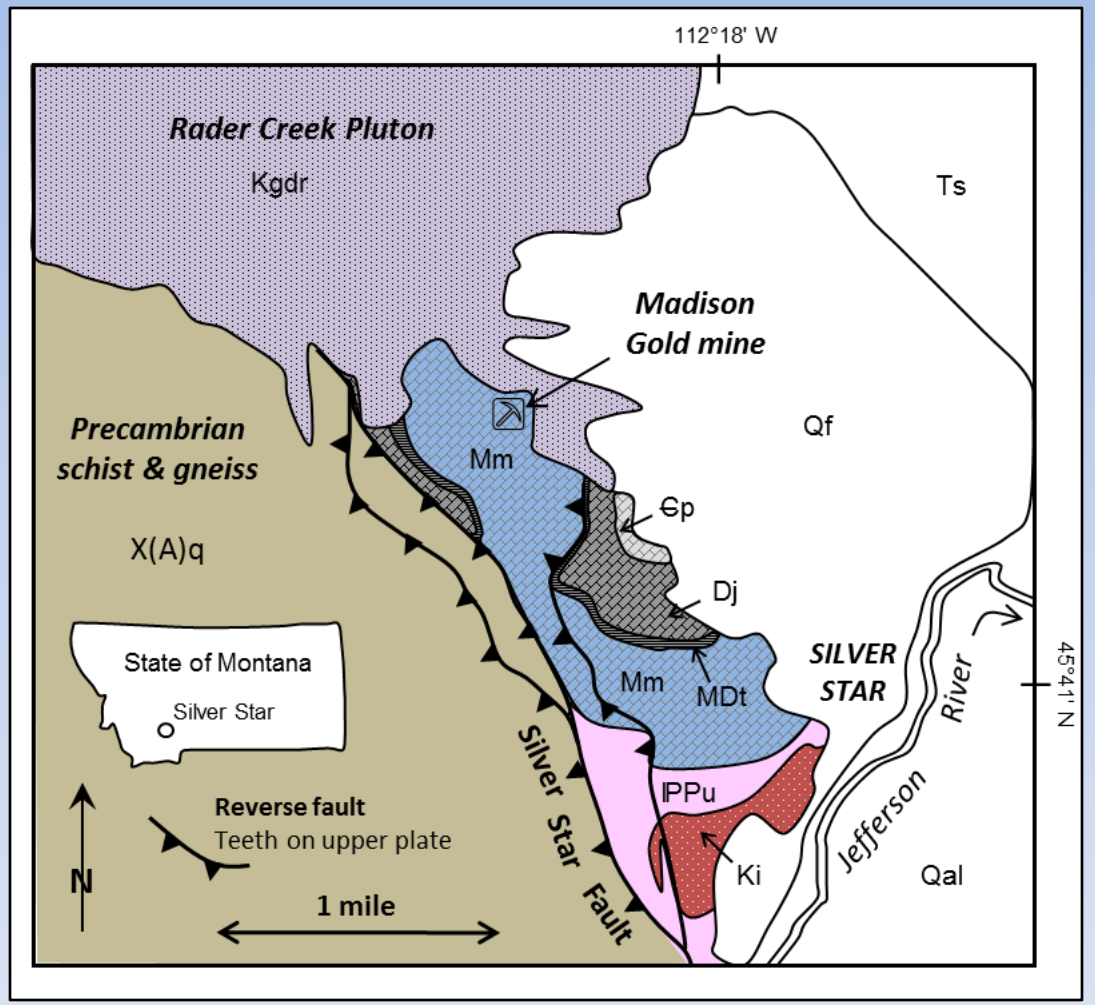
Butte Granite (bqm)
74.5 Ma (Lund et al., 2002)

Rader Creek Granodiorite (rc)
80.4 Ma (Lund et al., 2002)

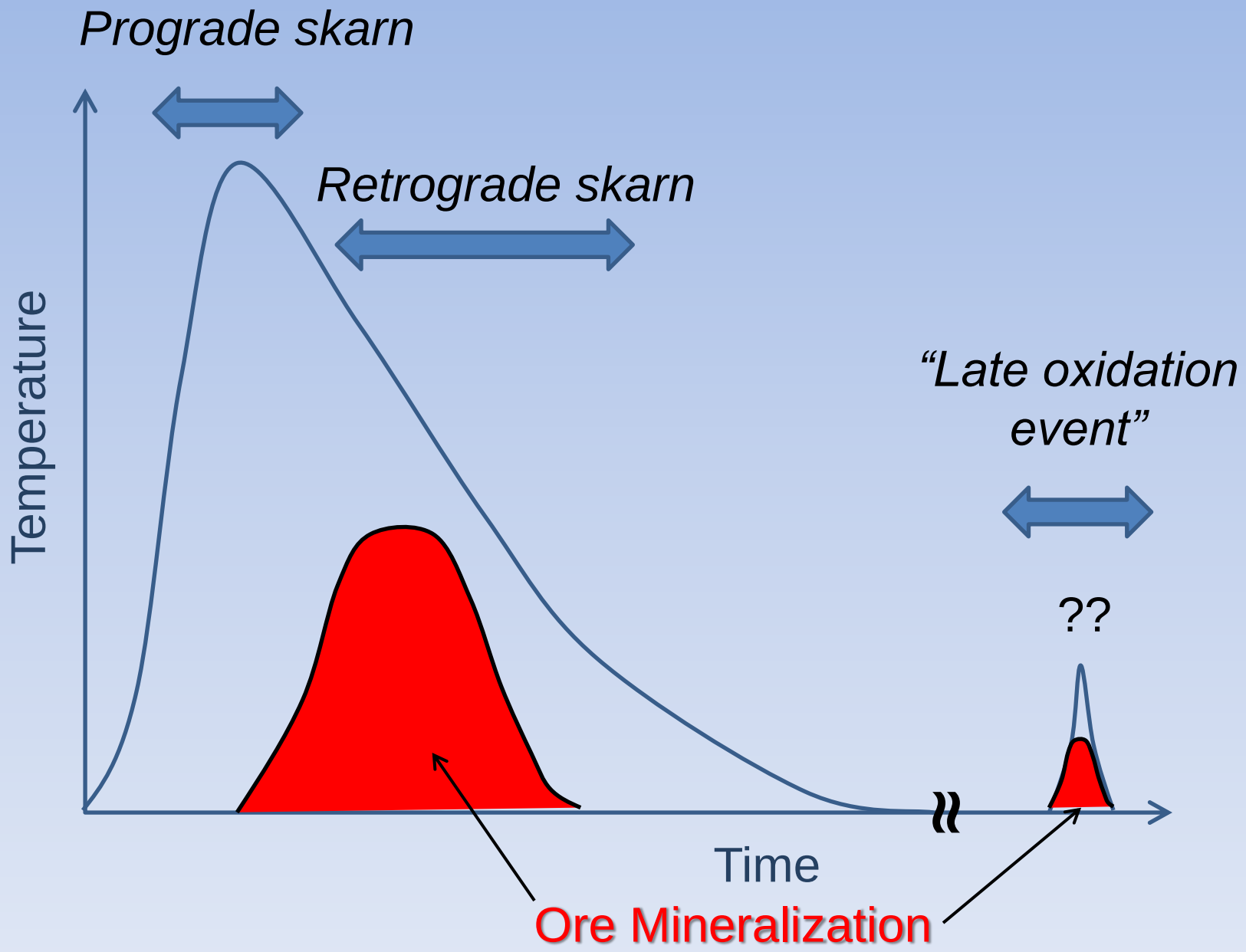

Diamond Hill
Au skarn
Elkhorn
Au skarn
Beal
Au skarn
Butte, Mt, USA
Highlands
Au skarn
Calvert
W skarn
Silver Star
Au-Ag-Cu skarn
Ivanhoe
W skarn
Image © 2013 TerraMetrics
Google earth

Local Geology

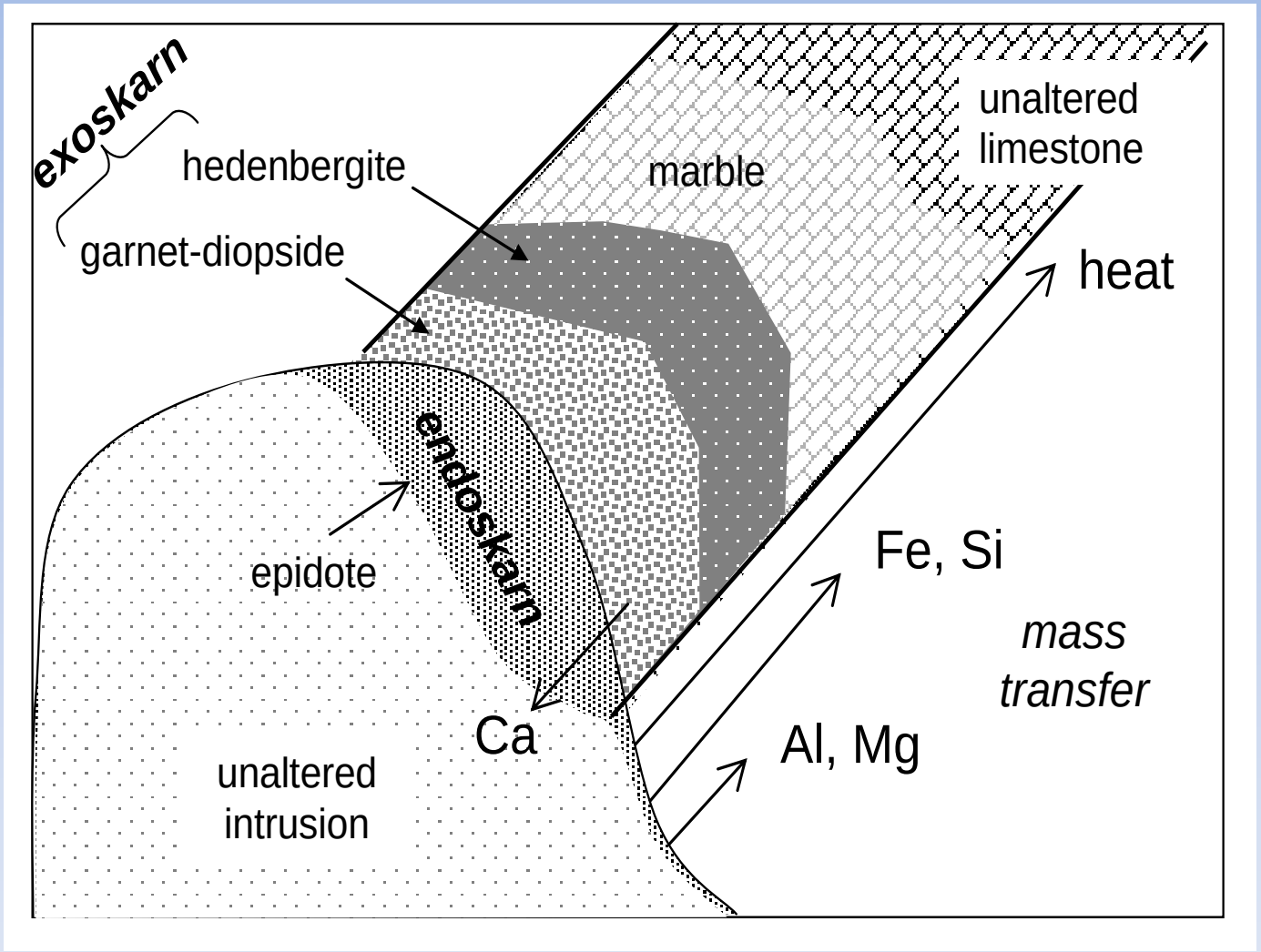




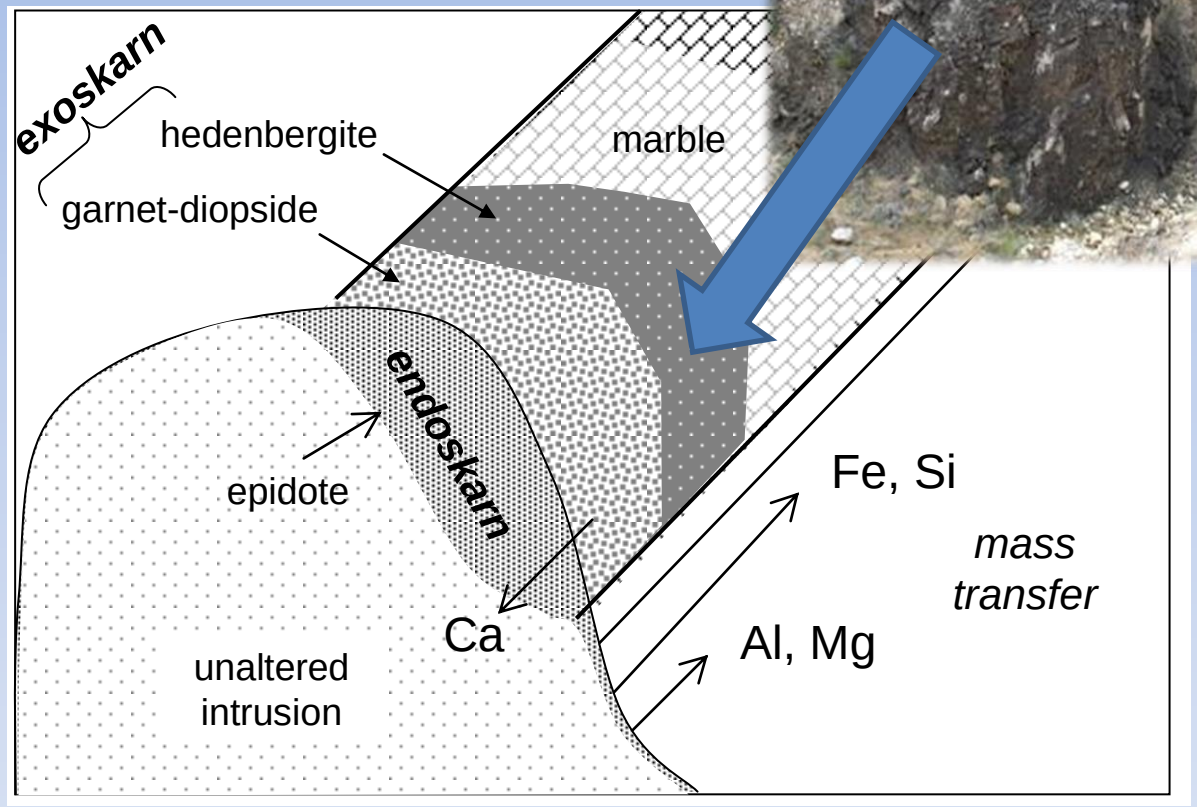
Simplified from O'Neill et al., 1996


Prograde skarn
Retrograde skarn
"Late oxidation event"
??
Temperature
Time
Ore Mineralization

Prograde skarn

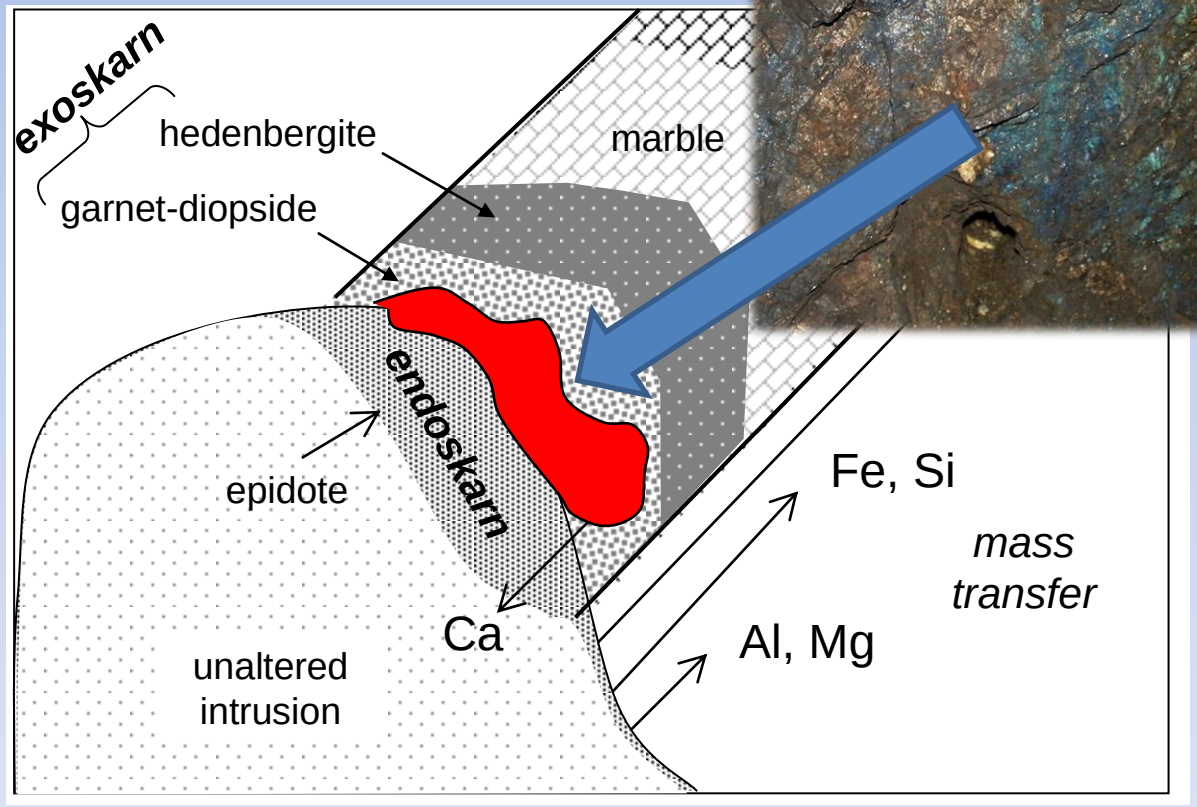


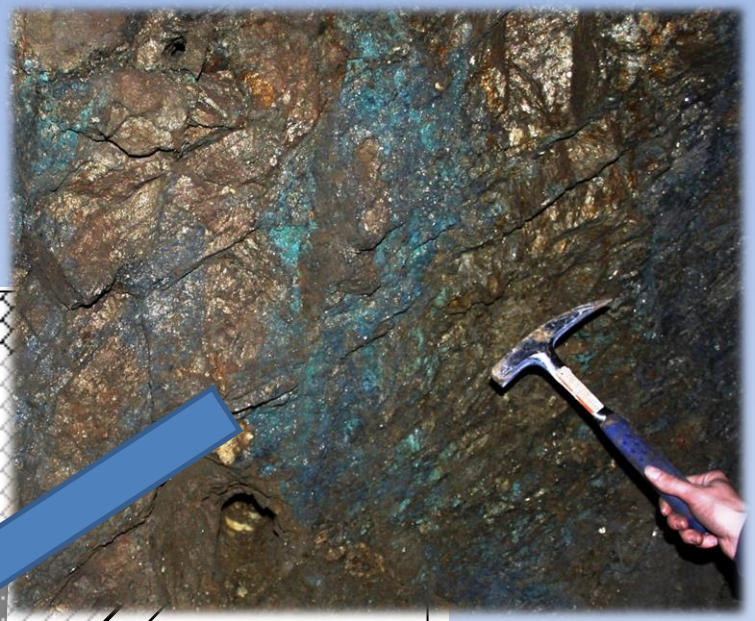
Prograde Skarn



$$CaCO_3 + Fe^{2+} + 2SiO_2(aq) + H_2O \rightarrow CaFeSi_2O_{6,\text{hedenbergite}} + 2H^+ + CO_2$$

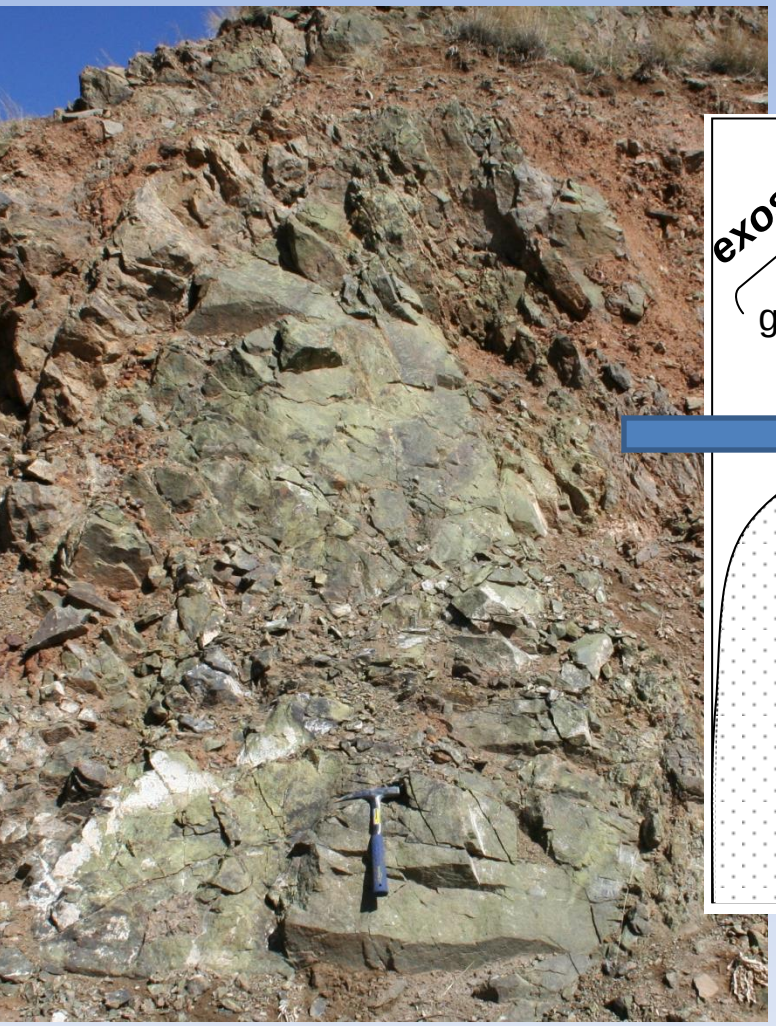
Retrograde Exoskarn

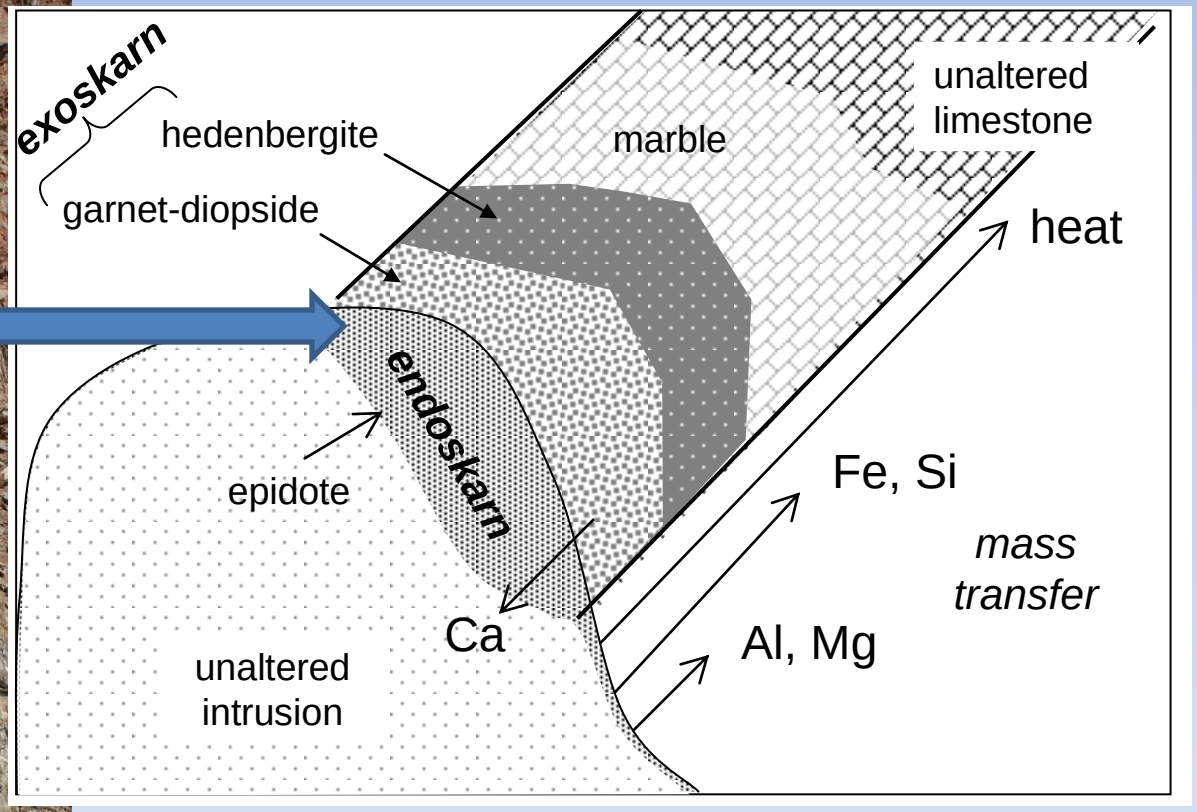




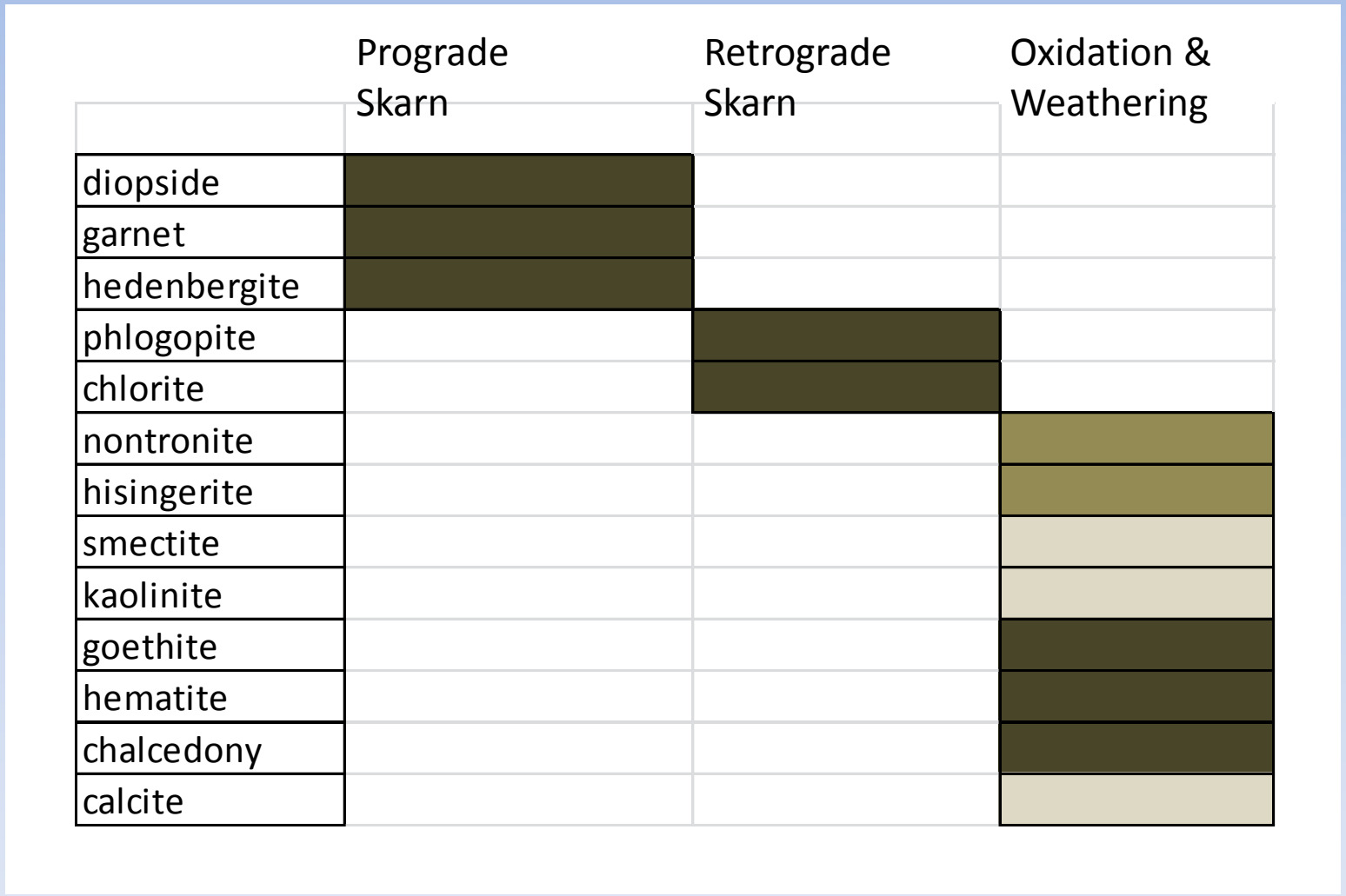
$$CaCO_3 + Fe^{2+} + H_2S + H_2O \rightarrow FeS + Ca^{2+} + 2H_2O + CO_2$$

Retrograde Endoskarn





Paragenesis: gangue minerals

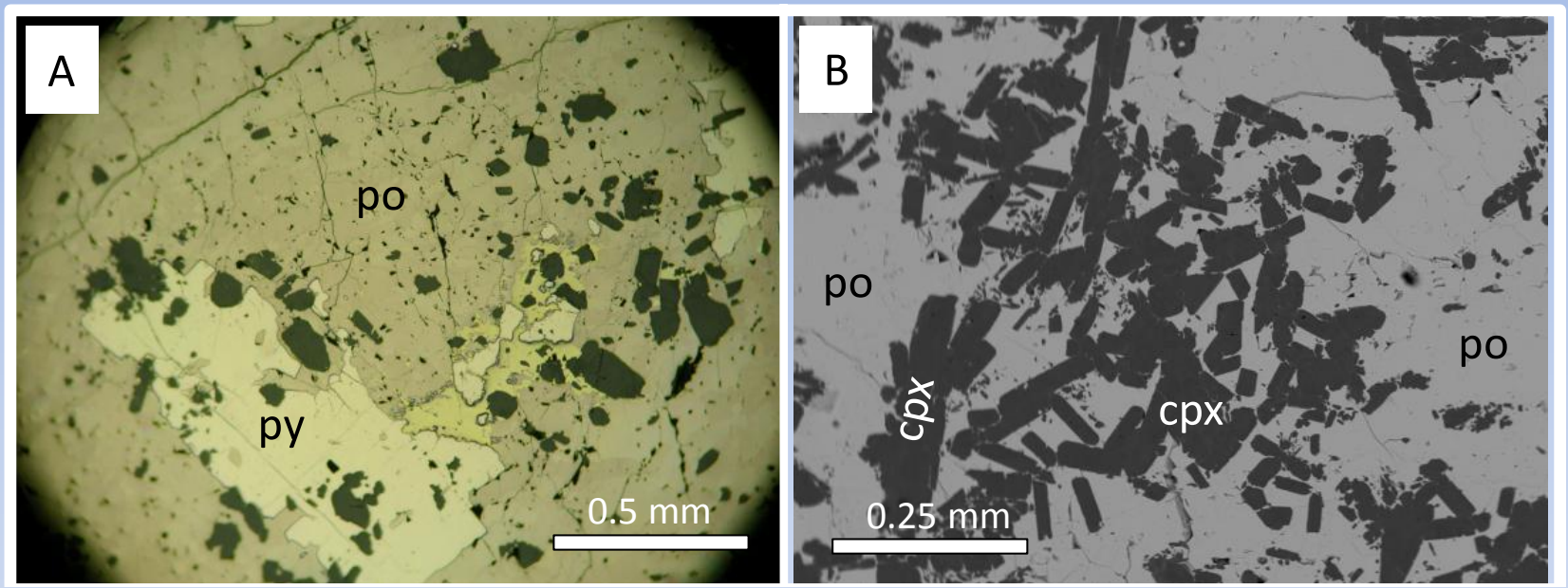


Paragenesis: ore minerals

	PROGRADE SKARN	RETROGRADE SKARN	OXIDATION & WEATHERING
pyrite			
pyrrhotite			
magnetite			
chalcopyrite			
bornite	??		
sphalerite		??	
galena			
electrum			
Bi-tellurides*	??		
hessite	??		
uraninite	??	??	
scheelite			
marcasite			
chalcocite			
copper			
cuprite			
tenorite			
gold			
silver			
CuI			

*includes tellurobismuthite (Bi_2Te_3), tsumoite (BiTe), hedleyite (Bi_7Te_3)

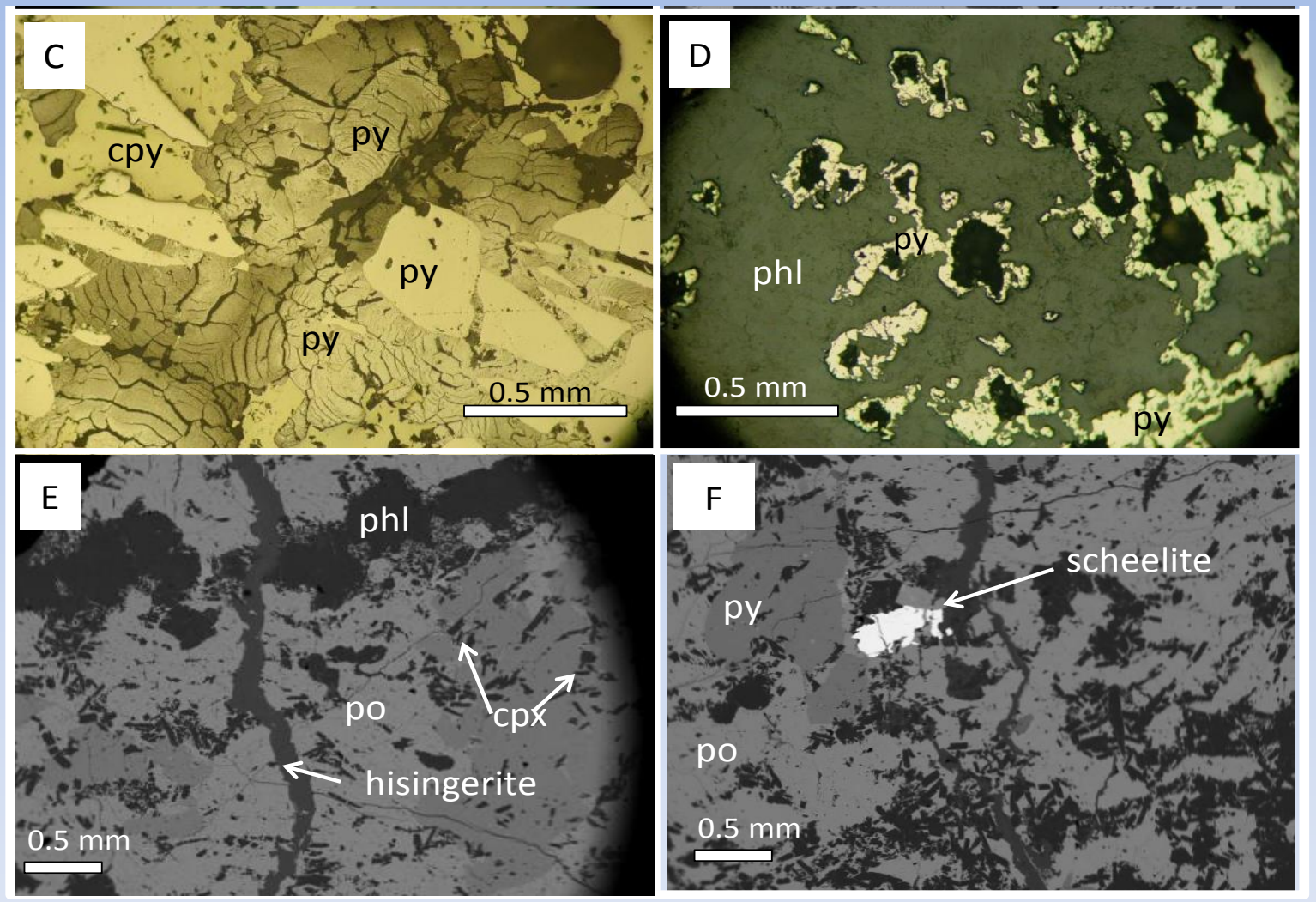
Prograde Mineralization



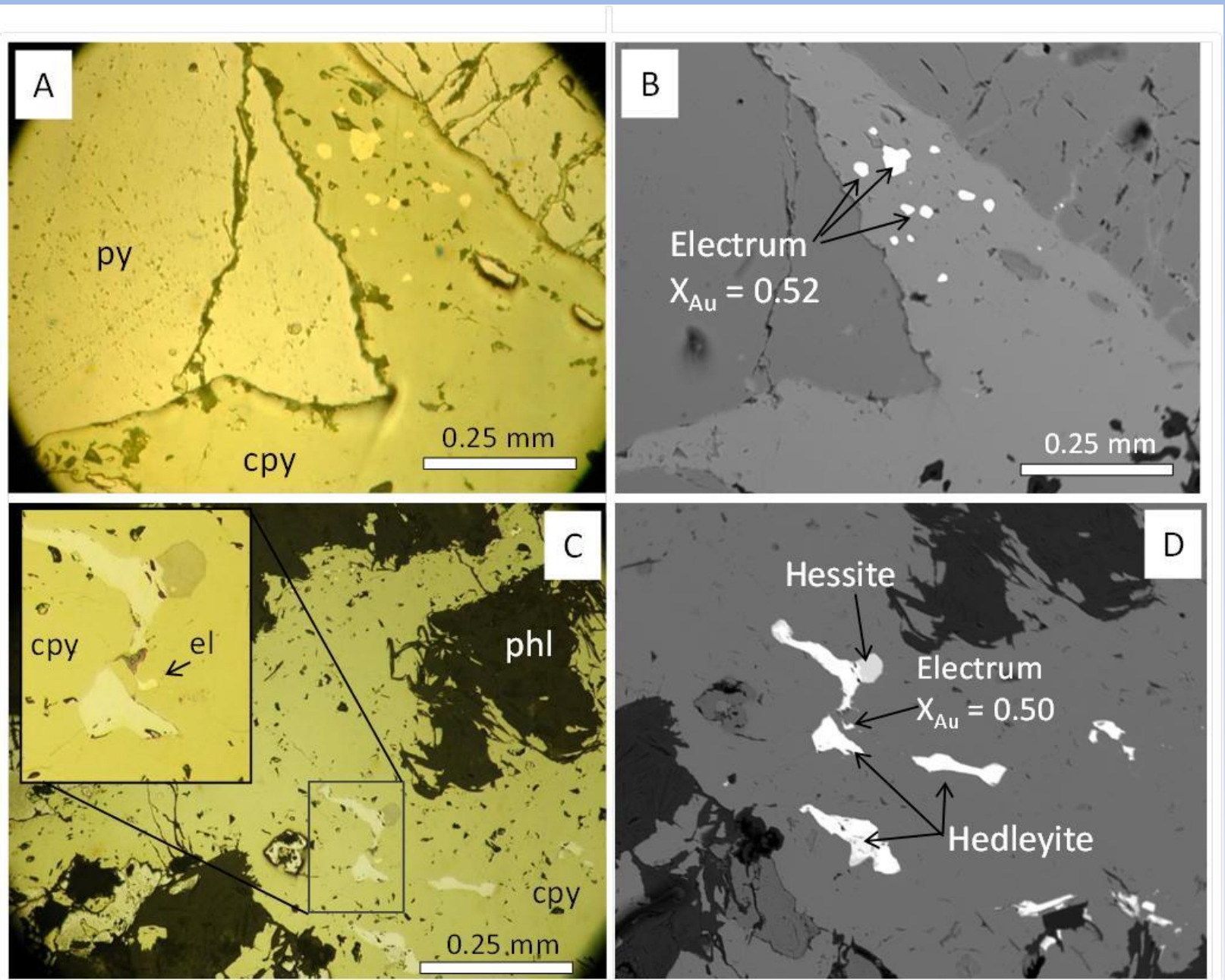
Reflected light microscopy

SEM-Backscatter Electron Image

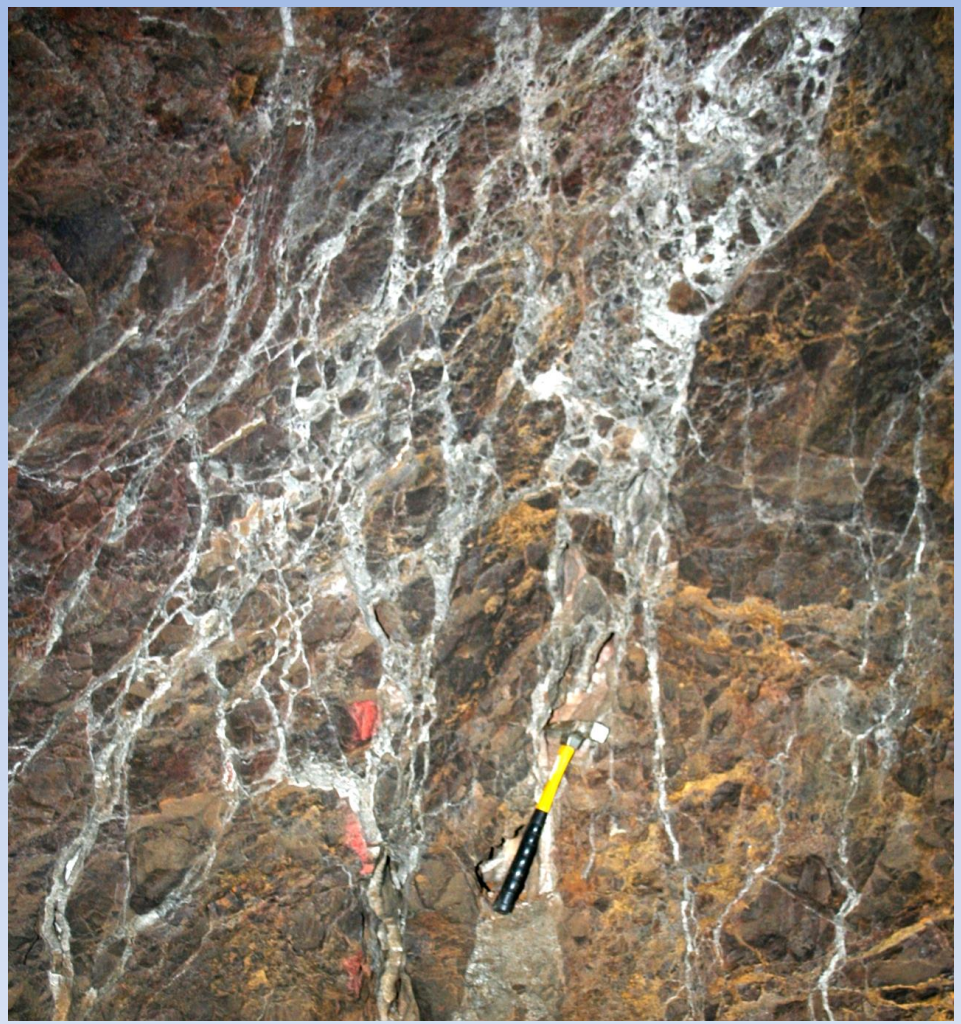
Retrograde Mineralization



Retrograde Mineralization Cont…

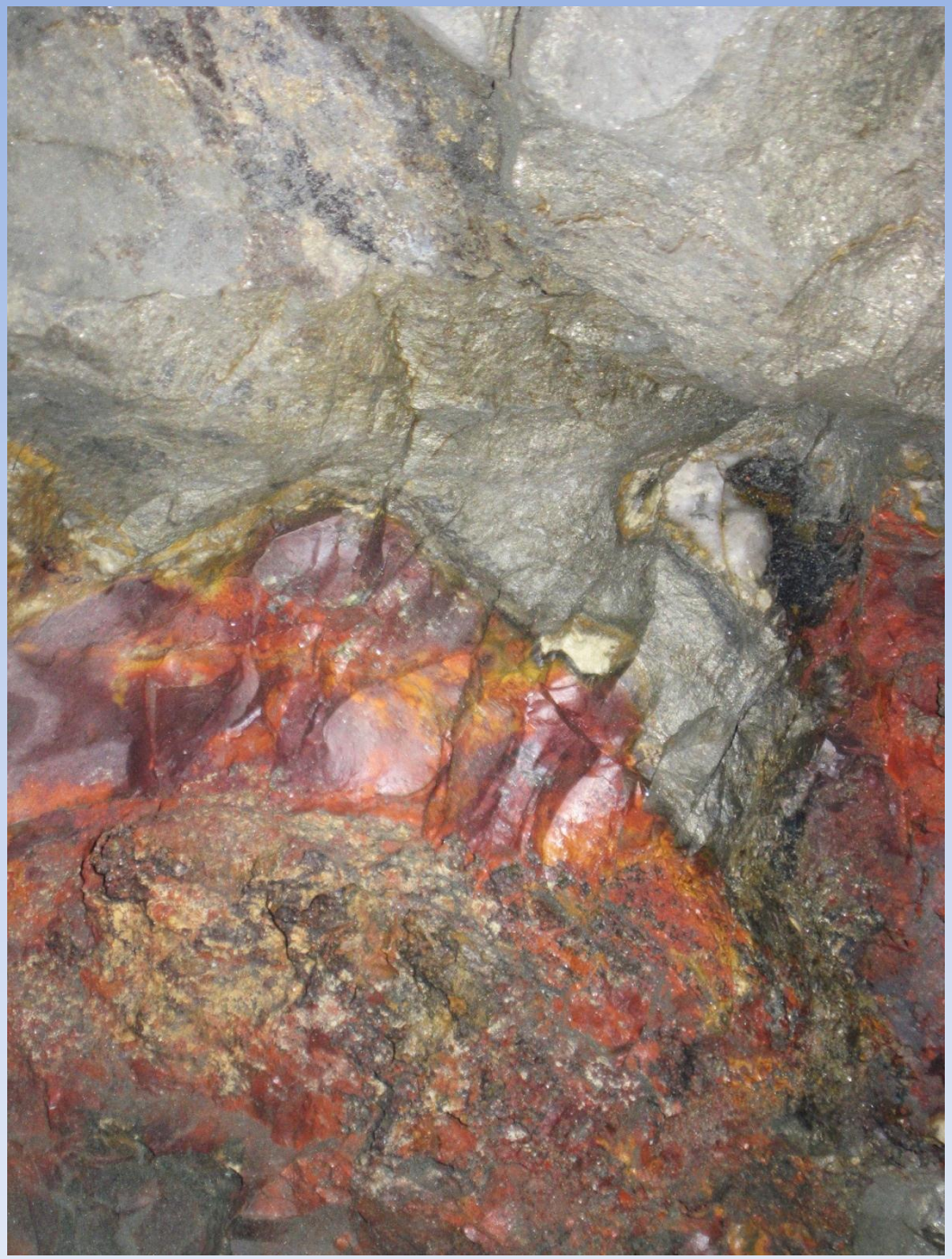


Late oxidation and silicification



Au-bearing jasperoid cut by calcite veins

red hematite pods (after chalcocite?)

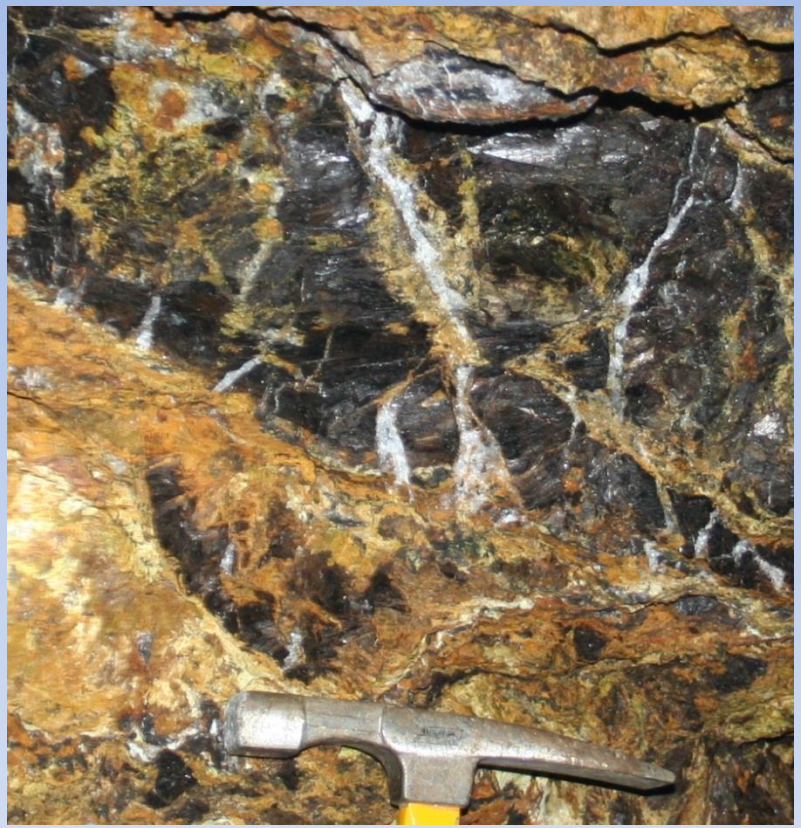


Jasper replacing massive sulfide

Doesn’t look supergene

Photo: Dan Everett

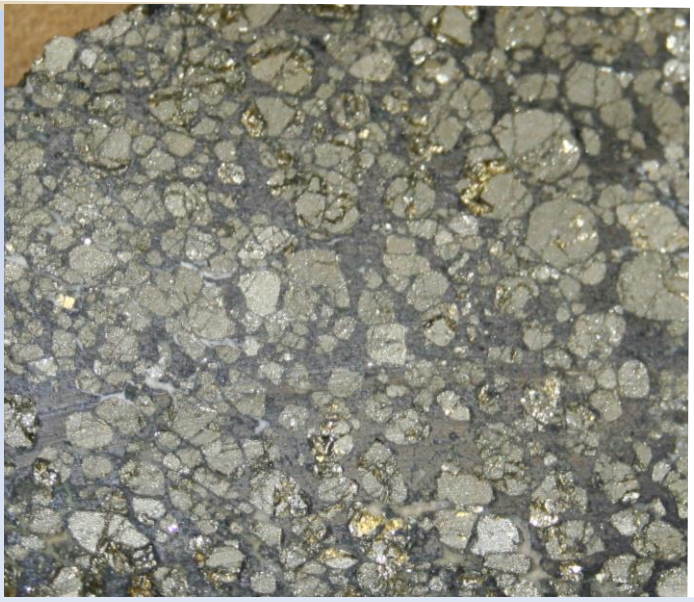
Breakdown of hedenbergite to nontronite



$$2CaFeSi_2O_{6,\text{hedenbergite}} + 2CO_2 + 2H_2O = Fe_2Si_4O_{10}(OH)_{2,\text{nontronite}} + 2CaCO_{3,\text{ calcite}} + H_2$$

Secondary enrichment of copper

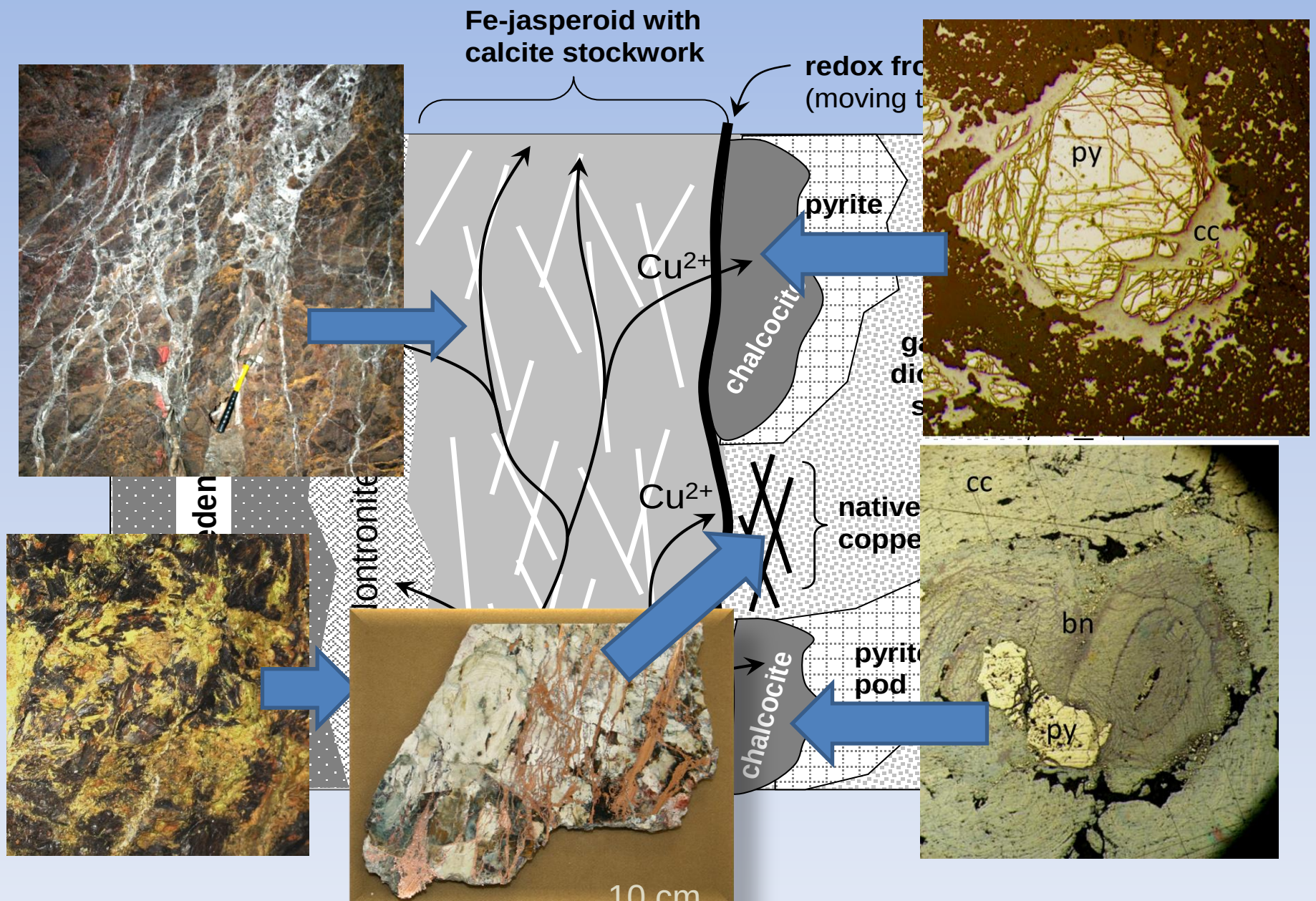
native copper pods and vein

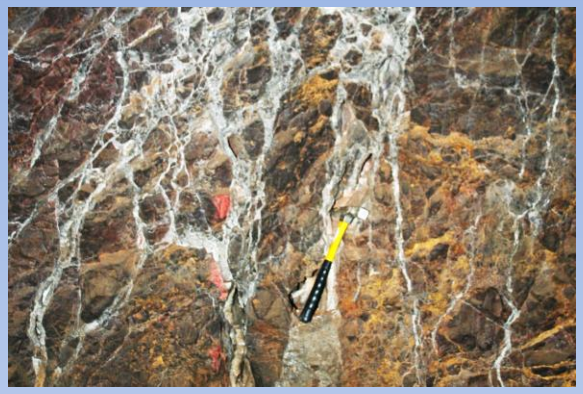


chalcocite replacing pyrite

20 lb Cu nugget.

Oxidation/Weathering Event

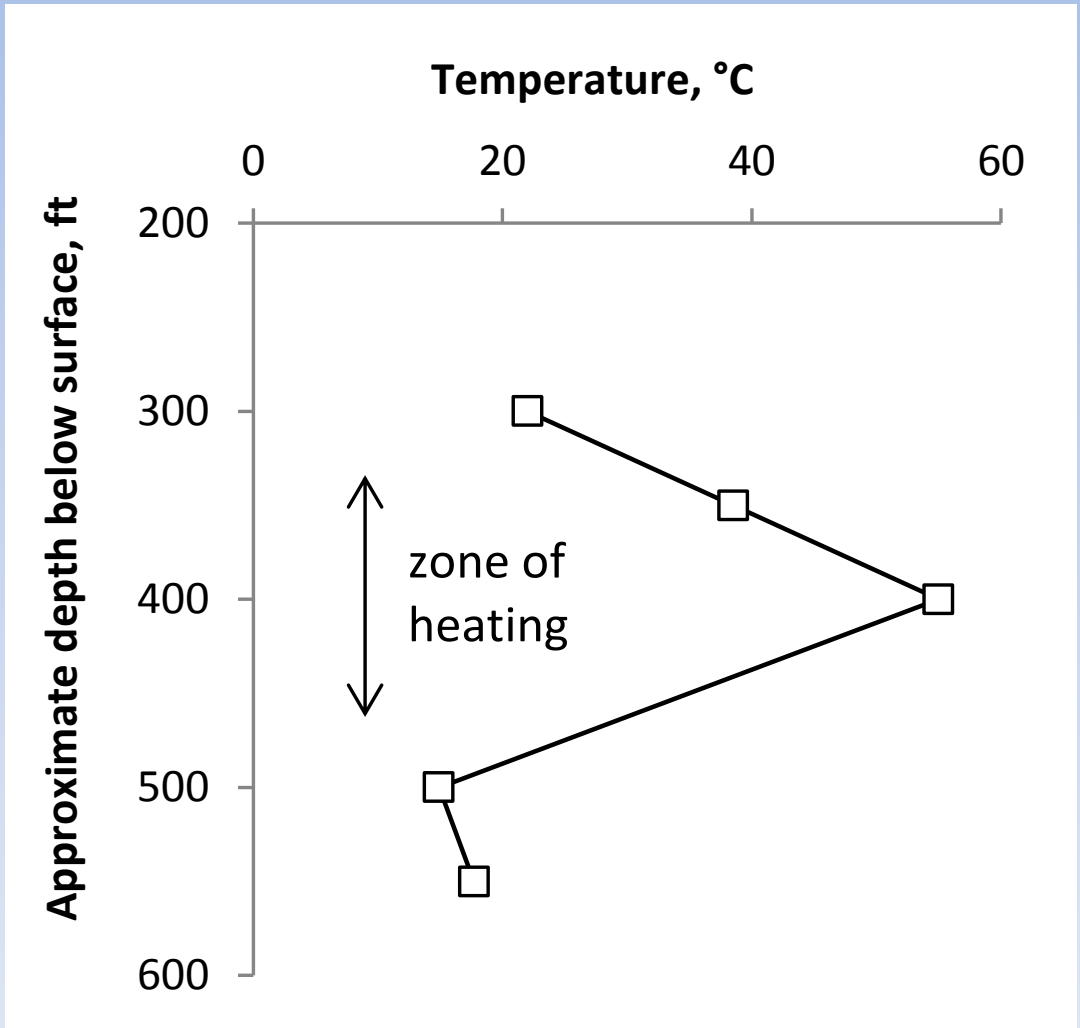




Temperature of Formation for Calcites Collected in the Mine

Location	Description	$\delta^{18}O$ of calcite $_{VSMOW}$, ‰	$\delta^{18}O$ of water* $_{VSMOW}$, ‰	Δ calcite - water	Temperature °C
300 level	Calcite vein	12.0	-18	30.0	22.0
350 level	Calcite vein	8.8	-18	26.8	38.5
400 level	Calcite vein	6.0	-18	24.0	55.0
500 level	Calcite vein	13.5	-18	31.5	14.9
550 level	Calcite vein	12.9	-18	30.9	17.7

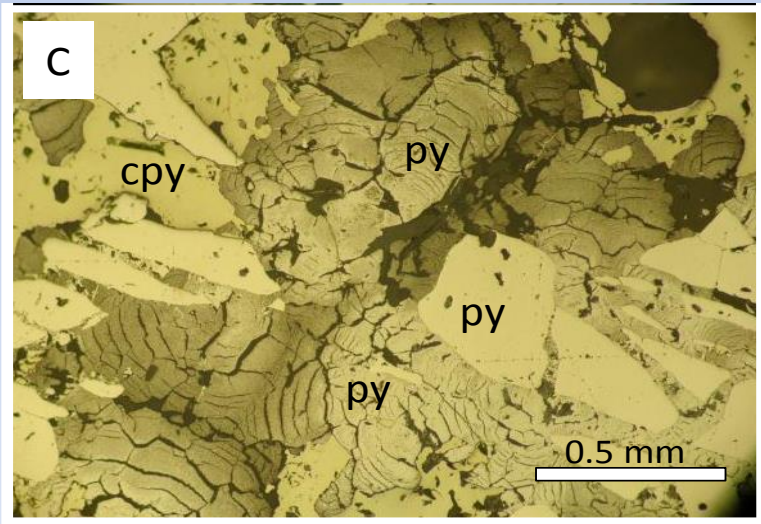
Temperature of calcite veins vs. elevation in mine



Pyrite and pyrrhotite oxidation is *exothermic* process

Pyrite + O_2 + water → H_2SO_4 + heat

Pyrrhotite + O_2 + water → H_2SO_4 + heat



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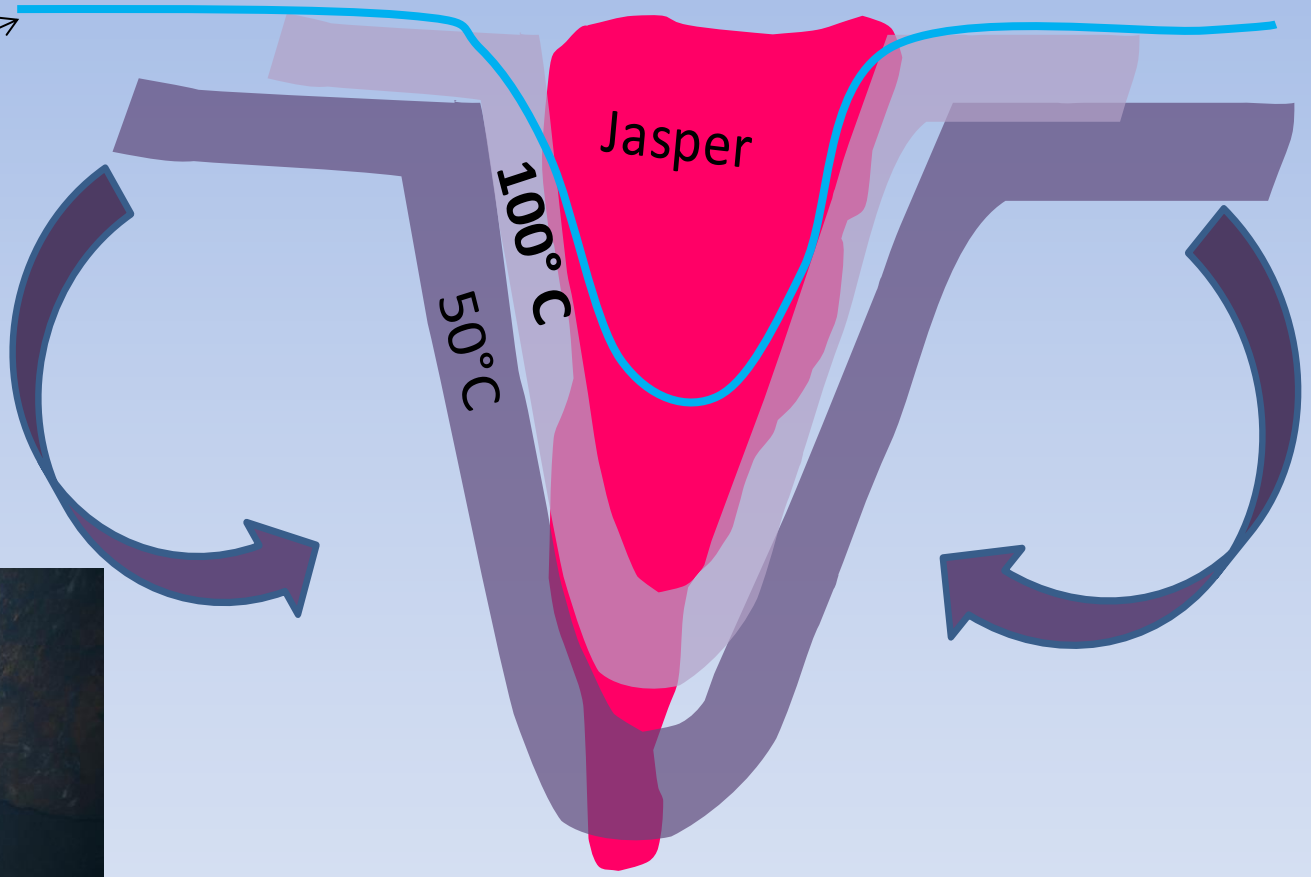
Hypogene Oxidation Model

Circulation and heating of O_2-rich groundwater



Summary

- Skarn mineralization
  - Pyrrhotite, pyrite, chalcopyrite
  - Electrum, Bi- and Ag-tellurides
- Late oxidation
  - Jasper (goethite-quartz) + calcite veins
  - Chalcopyrite → chalcocite, native copper
  - Gold stays put
  - “Self-heating” hypothesis?
- Source of mineralization?
  - Rader Creek pluton doesn’t look sexy enough
  - Possible Cu-porphyry at depth??

Questions?

Big thank you to Dan Everett and Coronado Resources for supporting the project and for giving Jill a job at the mine!

…and Gary Wyss for help with SEM!

Primary references

Sotendahl Jill (2012) Economic geology of the Madison Gold Au-Cu skarn, Silver Star District, Montana. M.S. Thesis, Montana Tech, Butte, Montana.

Gammons C.H., Sotendahl J., and Everett D. (2010) Secondary enrichment of copper at the Madison Gold skarn deposit, Silver Star district, Montana. *Northwest Geology*, v. 39, 15-24.